ROAD RESEARCH LABORATORY

A Review of Existing Methods of Road Construction Over Peat

Road Research Technical Paper No. 40

DEPARTMENT OF
SCIENTIFIC AND INDUSTRIAL RESEARCH

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THE ROAD RESEARCH LABORATORY of the Department of Scientific and Industrial Research is a government organization for studying problems that arise in designing, building and maintaining public highways. The primary objectives of the work, which is undertaken in close co-operation with the Ministry of Transport and Civil Aviation, are to improve the road as a channel for traffic, to reduce the overall costs of construction and maintenance and to promote safety and comfort in travel. The work is organized in two divisions: Materials and Construction, and Traffic and Safety. The principal subjects of study in the former are (a) soils and stones, (b) concrete roads, (c) bituminous surfacings, (d) road plant and machinery. Traffic and safety researches include (a) road layout and lighting, (b) surface characteristics, (c) traffic flow and movement control, (d) vehicle characteristics, (e) road user characteristics, (f) accident statistics. The Medical Research Council is collaborating in the work on road user characteristics.

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A Review of Existing Methods of Road Construction Over Peat

BY

J. O. TRESIDDER, B.Eng.

LONDON
HER MAJESTY'S STATIONERY OFFICE
1958

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FOREWORD

IN many parts of Britain, in particular Scotland, Northern Ireland and the fen country of England, there are deposits of peat and soft soils which provide particular difficulties in road construction. The problem can be overcome by complete removal of the peat and its replacement by fill material, but for economic reasons it has seldom been found possible in the past to do this in any but extremely shallow deposits. Roads built over peat are normally subject to considerable waviness and distortion and involve relatively high maintenance costs; they have, however, been tolerably successful as long as the traffic has remained light and high standards of speed or comfort have not been insisted on.

With the increasing weight and more exacting demands of modern traffic, however, more drastic measures are now required. This paper outlines the methods that have been developed in different parts of the world for removing peat and soft soils and for building over them. Although some of the methods appear to be successful under some conditions, none of them can be universally applied and many of them give very little guarantee of success; thus the general problem of road construction in areas of peat remains largely unsolved.

This paper represents the first stage in a programme of research on construction over peat; its main purpose is to present the background of the subject. It is thought that this summary of available information on the methods used both in Great Britain and in other countries may also be of some help to engineers confronted with this problem.

W. H. GLANVILLE,
Director of Road Research

ROAD RESEARCH LABORATORY,
February, 1958

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A Review of Existing Methods of Road Construction over Peat

INTRODUCTION

E of the most difficult problems that can confront a road engineer is the struction of a road over a deposit of peat or marshy soil. Some of the more sfactory methods of dealing with the problem, such as the removal of the t, can be very costly and may often be ruled out for that reason. On the other d, less expensive methods will often fail to provide a road structure that is up present-day standards. Thus no easy solutions are normally available. ertheless, some guidance can be obtained in designing and constructing ds over peat by studying the behaviour of previous construction and by ng into account what is known of the general properties of peat. In this way ay be possible to limit to some degree the undesirable features normally met uilding roads over peat.

n this paper an outline is given of the various methods that have been used Great Britain and abroad both in removing peat and in building roads over t is based largely on a survey of the world literature on the subject together a more detailed examination, on actual sites, of methods employed in at Britain and in Ireland.* A brief discussion is also given on the general perties of peat and the way in which they can be expected to affect road struction. References to further sources of information are given throughout text.

lthough peat is the material specifically referred to in this paper, the methods onstruction described can often be applied also to any marshy soil of a very nature.

GENERAL PROPERTIES OF PEAT AND THE PROBLEMS ASSOCIATED WITH THEM

t is essentially an accumulation of plant remains at various stages of de-position, formed in waterlogged areas, such as swamps or bogs. Although eral matter may be incorporated with it, it is predominantly organic in racter. Marsh soils, on the other hand, consist predominantly of mineral ter, usually of a fine silty nature, existing under waterlogged conditions.

t types

. K. Fraser[1] and others[2][3] have classified the more important types of t deposit according to various methods such as on the basis of origin,

this publication references to Ireland relate to Northern Ireland and the Republic of eland except where otherwise indicated.

occurrence, botanical composition, degree of humification and physical stru ture. These classifications are not, however, intended for use by road enginee and up to the present no significant differences in engineering properties ha been sufficiently well distinguished to enable a suitable system of classificati to be developed. In Great Britain it is usual for engineers to refer to only thr broad classes of peat:

Blanket moss (or blanket bog). Blanket moss occurs in extensive region deposits which cover the countryside usually to a depth of about 4 ft althou it may extend to depths of 10 ft or more in places. It is found typically in hi areas and its distinguishing feature is that it is not associated with a water-tab

Basin peat. Basin peat occurs as a local deposit in valleys, hollows and simil poorly drained areas. Its depth is, typically, between 10 and 20 ft and it always associated with a water-table, which is usually fairly near the surface the deposit. The term 'basin peat' includes 'raised moss', which is a more matur development of basin peat in which the top of the moss reaches to about 4 above the water-table.

Fen peat. Fen peat is a deposit of organic peat contaminated with silt a clay which has developed in lowland areas liable to flood and in the neighbou hood of calcareous rocks such as in East Anglia. The depths of these depos may vary from 5 to 50 ft or more. Fen peats tend to have lower moisture co tents, lower compressibility and slightly higher strength than other peats.

Variability

Peat is very variable in its properties, both from one deposit to another a from point to point in the same deposit. Such variations are associated with t origin of the peat, the type of plant from which it is derived, the mineral conte of the deposit and the amount of decay or humification that has occurred. these features are reflected in those properties, such as strength and compre ibility, with which the engineer is concerned. The variability of peat with dep is particularly noticeable because peat deposits are formed in layers which m differ considerably in their nature. Fresh fibrous peat tends to occur near t top of a deposit while the lower layers are frequently composed of soft, latively dense and highly humified material. At other levels decayed tree stum or peat with a plate-like structure derived from decayed rushes may be e countered, whilst on the surface of the deposit a tough mattress of vegetati of up to one foot in thickness is normally present. Although reasonably co tinuous, this surface mattress may itself be broken up into 'hags' or interrup by wet 'flushes' of softer peat. The mattress normally has appreciable streng in tension and can be used in helping to support fill material and constructio traffic; it is, however, liable to decay or to break suddenly at a later date.

In general it is the variability of peat in a horizontal direction that makes ro construction over it particularly difficult. These variations in properties, toget with variations in thickness, lead to differential settlements and to the consequ development of extremely wavy road surfaces; distortion and localized mo ment of the road surface also occur where softer portions of the peat beco overstressed.

Moisture content

One of the most distinctive features of peat is the very large amount of wa it contains. Moisture contents of over 1000 per cent by weight of dry peat usual. Associated with these high moisture contents are other properties such

strength, high compressibility and high shrinkage on drying. In general, drier peat is, the better are its engineering properties. Consideration is, efore, often given to methods of reducing the amount of water it contains. rt from the undesirable volume changes that such processes inevitably lve there is a limit to the effect that ordinary drainage measures can produce. s is due to the fact that much of the water present in a peat deposit is not water' but is held by the peat partly as capillary water, and partly in oidal form, in which the water is bound in cellulose and humus gels derived n humified plant remains.[4] The effect of drainage trenches is very local and ough significant reductions in moisture content can be made near the ace or immediately adjacent to the trench face, little can be done by this ns to reduce the moisture content of the general mass of deep peat under a cture such as a road. Furthermore, any drainage of this nature that is essful is very slow in taking effect. In Ireland, where peat is extracted from bogs for use as fuel, drainage trenches normally have to be dug four years re the adjacent peat has to bear the weight of the specially designed excava- machinery. A further difficulty of drainage occurs because basin peat and peat normally occur in low-lying areas, from which it is difficult to obtain able outfalls.

, however, peat is thoroughly dried (or merely air-dried), an irreversible nge takes place in the colloidal fractions and the peat will 'take up' only a ll fraction of the water it originally contained on being immersed again. s property favours any attempts that are made to use dried peat as a light- ght fill material.

sity

he dry density of peat is very low, usually of the order of 5 to 10 lb/cu.ft. e most peats are waterlogged the density is closely related to the moisture tent; thus the engineering properties associated with high moisture contents lly correspond with those associated with low dry densities, and vice versa. he bulk density of peat is only slightly higher than that of water, while ned peat often has a density which is the same as, or slightly lower than, of water. Fen peats may, naturally, have rather higher densities according e amount of mineral contamination.

is obviously desirable to reduce the load on a peat layer as much as possible the low density of peat relative to that of conventional road materials allows scope for doing this by any method involving the excavation of the top rs of the peat itself. While it is sound in principle to balance the weight of road material against the weight of peat removed, the depth of peat that to be excavated is so large that there are few opportunities of applying this edure.

r strength

is undoubtedly an over-simplification to refer to the complex rheological erties of peat under the general heading of 'shear strength'. As far as the tising road engineer is concerned, however, it is convenient to regard shear ngth as representing in practical terms one important aspect of the behaviour eat under load. The shear strength of peat is normally less than 4 lb/sq.in. very often of the order of 1 or 2 lb/sq.in. or less. Indeed the very weakness eat itself makes it difficult to prepare and test laboratory specimens that will vide an accurate evaluation of its strength. Nor is there any definite point of

failure, since very large deformations normally occur before the maximum lo is reached. When loads on peat are small or are rapidly applied, both elast and viscous properties are readily noticeable, elastic effects being particular associated with the more fibrous and less humified varieties of peat. Moveme of water within the peat when it is subjected to external stresses is also probab a feature of any deformation that occurs, and the pressure of the pore-water any point in the peat is normally considered to be an important factor in t mechanism of failure.

In general, however, the deformation of peat under load appears to appro mate to a condition of plastic flow. Plastic failure is a common feature of roa over peat even when the applied loads are comparatively small but it is diffic to determine precisely the state of stress at which failure commences. As example, drainage trenches in peat adjacent to roads are commonly seen bulge inwards progressively with time and often close up completely. Su movements are invariably reflected in the distortion of the road surface itse The outer edges of roads built on peat embankments are also found to si more rapidly than the rest of the structure. Significant increases in traffic al induce plastic deformation of peat subgrades to such an extent that many roa that had previously become relatively stable, have been known to suffer e tremely rapid deterioration of the whole road structure. This is a feature co mon to soils that fail plastically, but the low strength of peat makes su deformation particularly rapid and severe.

Except where peat is consolidated under the weight of overlying strata feature which is not common in Great Britain), it is usually found that there an increase in strength near the top of the deposit. In constructing a roa therefore, it is usually desirable to avoid breaking through into the softer pe beneath. If it is necessary, however, to build on soft peat, any disturbance of by constructional traffic may make it still weaker. A practical requireme brought about by the low strength of peat when stripped of its surface mattr is that any constructional layer that is placed immediately on top of it shou not contain large stone because the peat would normally be unable to withsta individual stones sinking into it.

The shear strength of peat increases when it is compressed. It is thus som times possible in embankment construction to avoid slips of the embankme material into the peat by carrying out the construction slowly in layers, allowi any excess pore-water pressures to be dissipated. In this way the effect of co solidation can be used to increase the strength of the peat until the full weig of the embankment can be carried; the rate of loading is usually controlled measuring the pore-water pressure in the peat and keeping it within safe lim

Compressibility

The very high compressibility of peat is another property that makes i most unsatisfactory material on which to build roads; large settlements produced by relatively small loads. However, when a load is removed from p after a period of consolidation very little recovery occurs. This means that o peat is consolidated under a load, such as a road structure, and the load is su sequently removed, the peat remains in a compressed state. In this condition shear strength is usually increased and its compressibility on further loadin reduced. It is thus found that when a road is constructed partly on pre-co solidated peat and partly on virgin peat severe differential settlements occ

; presents a serious problem in the widening of existing roads. On the other d, if a road can be built entirely on peat that has been pre-consolidated in e way, less serious settlements and deformation can be expected than in the of construction on virgin bog.

he consolidation of peat is a relatively complex process. Two distinct effects thought to occur. At first the process is largely governed by the rate at which er can escape from and through the peat. During this phase the process is lominantly a hydrodynamic one similar to that governing the consolidation lay, in which the time of consolidation varies as the square of the thickness ie layer concerned (i.e. the square of the length of the drainage path). There ie noticeable difference, however, in that the permeability of peat, instead emaining sensibly constant, appears to decrease significantly during the cess. This, coupled with the normal reduction in hydrostatic pressure ciated with the emission of water from the layers under load, means that solidation proceeds at an ever-decreasing rate. The time involved in this stage of the process of consolidation varies but is often very lengthy, and ie case of deep peat may continue for many years.

here is, however, a second phase of consolidation, known as 'secondary pression' in which settlement continues at a rate which is independent of the nage process and the thickness of the peat layer. This is thought to occur iltaneously with the primary consolidation but it continues long after iary consolidation has virtually ceased. It is difficult to define precisely the es of secondary compression but the phenomenon can be observed particul- clearly in the consolidation of peat. In laboratory tests, compression of the when under load has been found to continue very slowly for several years.

oads over peat can thus be expected to settle (and, usually, to settle differ- ally) for a considerable period of their existence. The greatest amount of ement takes place in the early life of the road, however, and it is therefore n desirable to defer the application of a final surfacing until much of this ement has taken place. The magnitude and rate of settlement vary con- rably according to the intensity of loading, the depth of peat and type of . Sometimes the majority of the settlement is virtually complete in a matter ionths, but on other occasions, where this is not so, it is sometimes possible ccelerate the rate of settlement of a road on peat by applying a larger load y reducing the length of the drainage path of the pore water escaping from the . Measures such as reducing the length of the drainage path can, of course, an effect during the primary (or hydrodynamic) phase of consolidation only. ir usefulness depends on the relative magnitude of the settlements associ- respectively with the primary and secondary phases of consolidation, as as on the time factors involved. The most suitable conditions for measures his kind have in practice usually been provided by very deep deposits of sh soils.

nkage characteristics

onsiderable shrinkage occurs when the moisture content of peat is reduced. makes the drainage of peat a procedure of very doubtful merit if it is ied out after the construction of a road, even though the shear strength of peat may be increased by this procedure. Trees and shrubs close to a road peat should be removed because they extract large quantities of water 1 neighbouring areas and they can produce severe distortion of the road

surface. Embankments of peat are particularly subject to volume changes sin the sides of embankments are exposed to the effects of weather, and differenti shrinkage and swelling of the peat occurs seasonally.

CONSIDERATIONS IN THE DESIGN OF ROADS OVER PEAT

In constructing a road over peat the class of road required largely determin the design and methods to be used; where a modern trunk road built to relative high standards is needed, difficult decisions may have to be made.

Methods of removing the peat are usually considered first. If the peat shallow, say, less than 6 ft deep, this usually presents very little difficulty and t work can be carried out by conventional methods of excavation. Even if t deposit of peat is deep, every effort should be made to secure its removal order to ensure a completely satisfactory road. Removal becomes increasin expensive, however, as the depth of peat or soft soil becomes greater, due n only to the cost of removal of the peat itself but also to the cost of supplying t large quantities of backfill material required. If removal is decided on f depths greater than 6 ft, the most satisfactory way of doing the work is usua to use an appropriate method of bog blasting, since these methods are the sure and enable the maximum amount of control to be maintained over the wo Alternatively, the peat may be removed by gravity displacement or by wa jetting, depending on local conditions; the most likely procedure in practi is for a combination of all three methods to be used.

If local conditions, such as the presence of buildings founded on peat or s soil close to the line of the road, preclude the use of any methods of removi the peat, consideration should be given to building such sections of the road piles. Although piling is extremely expensive and has therefore not often be used, the unsatisfactory nature of any possible alternative measures may w make the use of piles necessary. It should be pointed out, however, that metho of removal, such as bog blasting, do not create as much general disturbance may be thought and their use is not necessarily precluded by the presence buildings in the vicinity. The movement of the peat can usually be directed aw from any existing structures and the temporary use of sheet piling to prot the foundations of buildings may sometimes be all that is required. Remo of the peat will entail the considerable expense of moving any services, such water mains and electric cables, which may be buried in the peat close to proposed new road. However, much of this expense is likely to be incurred any case in time, whatever form of construction is adopted, due to the servi being fractured through movement of the peat.

If the costs of removing a section of peat or soft soil are prohibitive, a meth of accelerated settlement, e.g. the use of vertical sand drains, may be tried. T normally requires special plant and for it to be economic, the amount of wo of this type being carried out should be reasonably large; in practice, also, large depth of peat or other soil must be involved to make the work wor while. Consolidation tests should be carried out and an assessment made of t amounts and rates of settlement that will occur before and after the completi

he road. It has usually been found that considerably greater advantage is ained from the use of vertical sand drains in marsh soils than in peat itself.

' it is decided that methods of accelerated settlement, piling, or removal of peat, are impracticable, methods of direct construction on the peat must be rted to. None of the methods available, however, give any guarantee that e deformations of the road surface and high maintenance costs will not sequently become a permanent feature of the road. It has been estimated a modern high-class road built over peat can cost up to £10 000 per mile annum to maintain in a satisfactory condition. Considerable thought should, efore, be given to the question of possible maintenance costs before any posals for removing or pre-consolidating the peat are abandoned.

1 the construction of roads directly on peat it is obviously desirable to keep load on the peat small. Where possible, therefore, the road layout should be 1 that no large depths of fill are involved. It may also be possible to derive efit from partial excavation of the peat and the use of light-weight materials orm a 'raft' type of construction. It is desirable that the weight of the cture should be distributed evenly and to this end berms outside the road of value. A choice has to be made between the use of flexible and rigid struction. Where site conditions favour a light construction the use of crete may be preferred. Whichever type of construction is used, however, rmation is likely to occur; thus the ease of applying remedial measures to bly constructed roads must be weighed against the fact that this type of road probably fall into disrepair at a considerably earlier date. It may be that a dwich' construction, in which flexible construction is placed over a concrete , or the use of prestressed concrete could form a reasonably satisfactory 1 structure. Such methods should only be attempted, however, when site ors and road layout combine to favour as light a form of construction as sible.

'here site levels are such that relatively heavy construction on an embank-t is unavoidable, flexible construction is almost always to be favoured. The struction of the embankment should take place as long as possible in advance ie time of construction of the final road surface; in this way slow construc- can be carried out to avoid shear failures of the peat and to enable as much olidation as possible to take place before the road is surfaced.

se can be made of advance construction of this nature to carry out drainage sures in the proximity of the road with the object of increasing the shear igth of the surface layers of peat; otherwise any drainage measures should pplied very cautiously, if at all, because of the risk of inducing undesirable me changes and of removing lateral support to the peat under the road.

the construction of minor roads over peat where the traffic is relatively and the standards required are lower, direct construction on the peat has iderably more chance of success. The possibility of removing the peat ld still be considered but this is usually too costly if the peat is deep. With educed thickness of pavement that can be used on minor roads there is scope for taking advantage of any possibilities of raft construction. Where oad is not on an embankment, concrete can appropriately be used; it can ide a reasonably good construction for a period of twenty years or more. neral, the design of a minor road over peat should aim at as uniform a ruction as possible, whether flexible or rigid construction is used.

REMOVAL OF THE PEAT AND REPLACEMENT BY FILL MATERIAL

Replacing the peat by good fill provides a sound road foundation but this is often considered uneconomic except for shallow deposits or for main roads carrying heavy traffic. Where the road must run close to buildings, sheet piling may be required to protect their foundations as the peat is being removed.

Mechanical excavation

Mechanical excavation of peat can be carried out using normal contractor's plant such as draglines (Fig. 1).[5] Dibbits[6] has described some work in Holland in which peat was removed in this way to a width of 25 metres and a depth of 3 to 4 metres for a length of 12 km (7 miles). Figures vary for the maximum

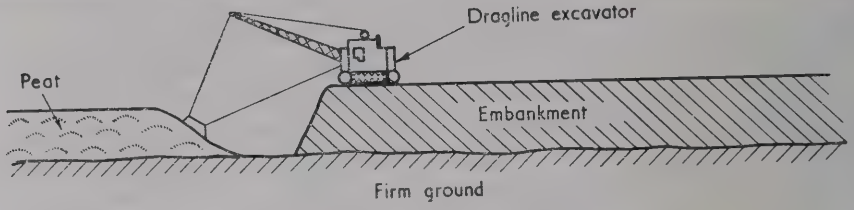

FIG. 1. COMPLETE EXCAVATION

depth of peat that it is an economic proposition to remove; Colley[7] suggests 6 ft as representing recent practice in the U.S.A. while Markwick[8] in 19… gave 12 ft for U.S.A. practice and 18 ft for German practice; 12 ft has been recently stated as the maximum depth in Holland. In some areas, however, such as in the north-west Highlands of Scotland where the roads carry relatively small amounts of traffic, the maximum depth excavated is usually 2 ft, and, at the most, 4 ft.

Excavation sometimes becomes impracticable in deep peat due to the flow of soft material into the excavated area at a rate faster than that at which the work can proceed.

Displacement by gravity

Some peats are soft enough to be displaced sideways by the weight of an embankment built upon them which settles until it rests on firm ground. The principal methods of displacing the peat are:

End tipping (*Fig. 2*). In this method, as described by Cushing and Stokstad

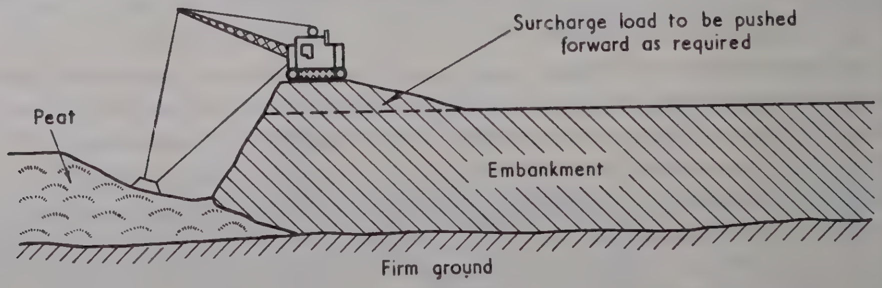

FIG. 2. THE 'END TIPPING' METHOD OF GRAVITY DISPLACEMENT

(partial excavation is used as a necessary aid to this process)

e embankment is slowly advanced along the line of the road by depositing at the head and by excavating the peat in front of the head and depositing it the sides of the advancing fill. This process is straightforward but slow.

Asymmetrical side tipping (*Fig. 3*). In this method the sand fill is laid along one ge of the proposed embankment and a trench 9 to 12 ft deep is then dredged ng one side and filled with sand. As filling is continued the peat is displaced one side of the embankment where it is removed by normal methods of

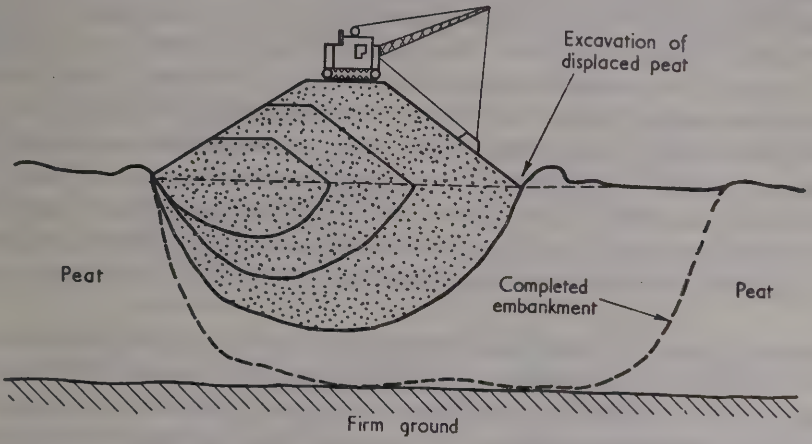

FIG. 3. THE ASYMMETRICAL METHOD OF GRAVITY DISPLACEMENT

avation, until an embankment of the required width and depth has settled ly into place. The method can be carried out in locations where buildings airly close to one side of the road. Both the above processes ensure practic- complete removal of the peat but entail the handling of considerable ounts of peat and fill.

ymmetrical side tipping (*Fig. 4*). This method is used in Holland[6] for con- cting main roads. The fill material, usually sand, is deposited over a shallow h cut through the surface mat of peat to the depth of the water-table along

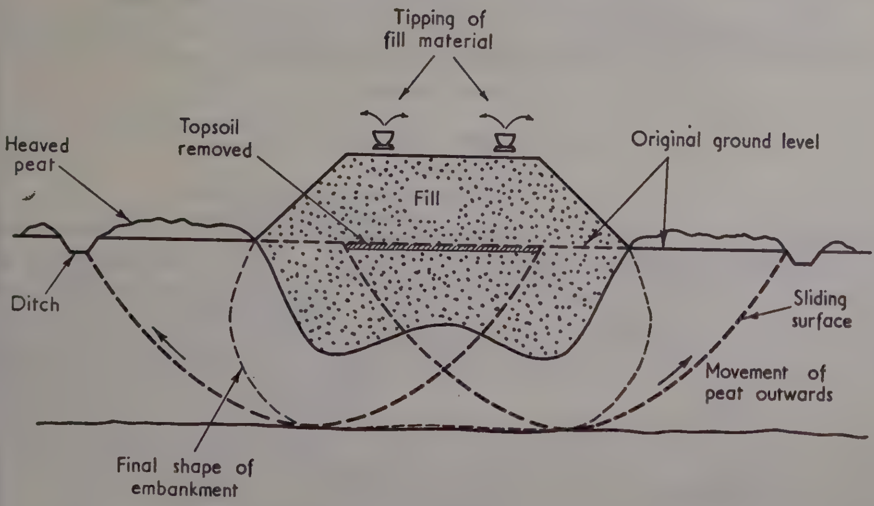

FIG. 4. THE SYMMETRICAL METHOD OF GRAVITY DISPLACEMENT

the centre line of the road to form a plane of weakness in the peat. Further is then added symmetrically on either side of the centre line until its weig displaces the peat and heaves it up on either side. This movement of the peat helped by cutting more ditches in it. Dibbits[6] and Hanes [10] give evidence th this process needs careful control; peat is often left under the embankment a this gives rise to further settlement. In one case differential settlement of embankment took place in amounts of up to 10 ft and side slips occurred duri construction. Where clay was used as the fill, deep cracks subsequently appear in the shoulders of the bank. The embankment was not sufficiently wide and upheaved peat folded back over it at certain places. Under these conditions took 15 months to construct a length of 500 yd of the road. Even then spec measures were called for, such as the use of stabilized gravel and metal tracki in the construction of the embankment, and the continued movement was s sufficient to prohibit the laying of a surfacing at the end of that time. Dibb reports that symmetrical tipping also tends to give rise to weak shoulders d to poor lateral penetration of the fill—in one case, over a period of four yea the outer edges of a dual carriageway settled 49 cm (19 in.) relative to the inn edges.

In general, gravity displacement appears to be most useful at sites where peat is relatively soft and where a plentiful supply of granular fill material particular, sand) is available. It is likely to be slower than displacement by bla ing or jetting, but the principle of the method can be used to assist these tv processes. The method has not been used in Great Britain except in this way.

Bog blasting

Explosives have been used, principally in America, Germany and Northe Ireland, to blast away peat either in front of or underneath embankments. T principal methods of blasting are:

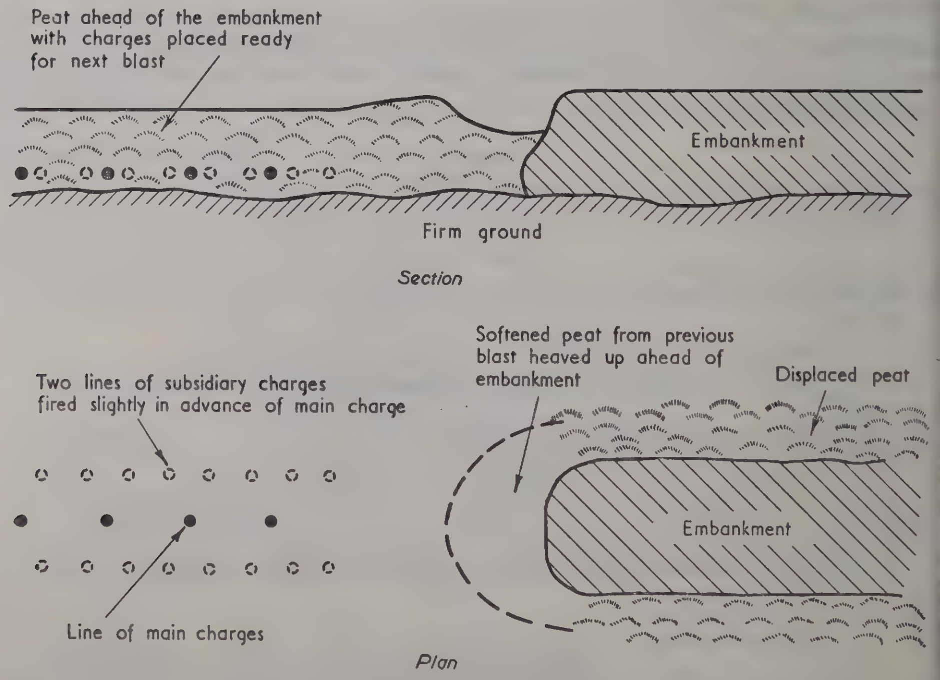

FIG. 5. THE TRENCH-SHOOTING METHOD OF BOG BLASTING

'rench-shooting (*Fig. 5*). In this method the explosive charges are placed near bottom of the peat in longitudinal rows in front of the embankment being ıstructed. When they are fired, an open trench is formed into which further material is placed. This method is used for depths of peat of up to 20 ft, and specially suitable for fairly stiff peat that is not liable to slip.

'oe-shooting (*Fig. 6*). In this method the end of the embankment is advanced l its height is raised until the peat is forced up ahead of it. Charges are then ced in the peat immediately in front of the toe of the embankment and are d simultaneously. The embankment then drops into the space left by the

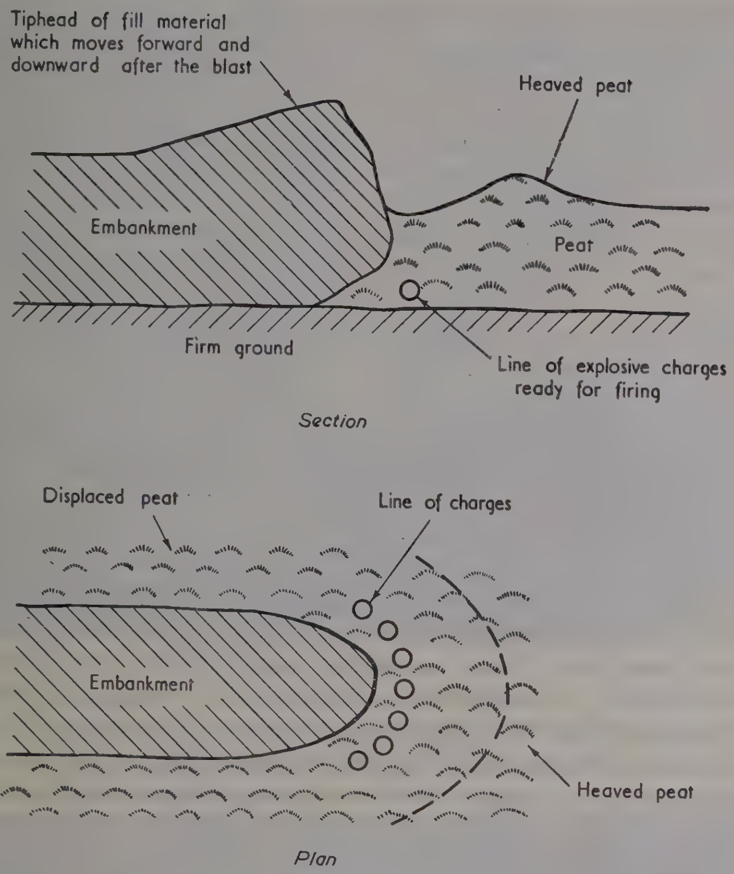

FIG. 6. THE TOE-SHOOTING METHOD OF BOG BLASTING

laced peat. Like trench-shooting the method is used for moderately shallow hs of up to about 20 ft; it is particularly suitable for fairly soft peats which almost soft enough to flow by gravity displacement alone. For deeper ›sits, up to about 50 ft thick, the peat can be displaced in the same way if posts carrying charges at various depths on each post are used. The method en known as 'torpedo blasting'.

nderfill blasting (*Fig. 7*). In this method an embankment is laid over the peat charges are placed underneath it, usually in three rows, a row of main ges under the centre of the embankment and a row of subsidiary charges r each edge. The subsidiary charges are detonated a second or two before nain charges so that the peat is blasted outwards in the most effective way.

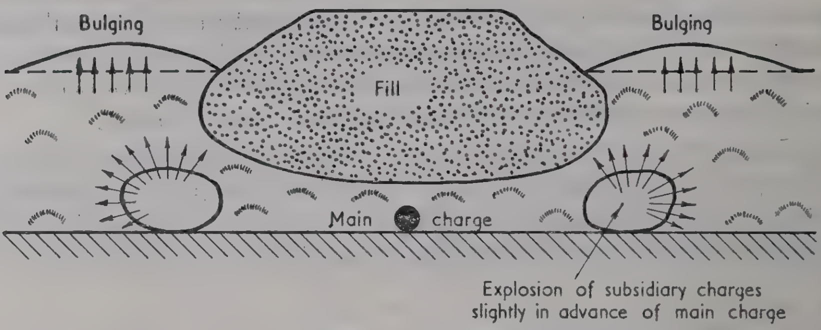

FIG. 7. THE UNDERFILL METHOD OF BOG BLASTING

This method can be used for any depth of peat, although for the greater dept several series of blasts may be required. When the peat is over 30 ft deep, wi embankments are built by constructing a narrow embankment first and th widening it either on one or both sides by further underfill blasting.

In bog blasting the charges are usually placed in the peat with the aid of wa jets. This requires special equipment together with an adequate supply of wa near at hand. With underfill blasting the fill must be a fine-grained granu material such as sand so that the jets can penetrate the embankment as well the peat.

In Holland, Dibbits[6] reports that bog blasting is not favoured since expe ence has shown it to be less satisfactory than gravity displacement. The Michig State Highway Department[11] has published information on the success use of the method in the U.S.A., although Colley,[7] in describing practice Florida, points to "the extreme cost of the method and the difficulties countered in placing and shooting the charges"; there the method is o considered applicable to depths ranging from 6 to 20 ft. In Germany b blasting has been used fairly extensively and Usinger and Garras[12] ha described a number of examples in which various methods of blasting w used. Full details of the equipment and explosives necessary for this work given by Duncan, Dalzell and Williams,[13] who describe the use of all th methods of blasting on a bog in Northern Ireland. Experience both in North Ireland and in Germany indicates that bog blasting is both a practical and economical method for main-road construction. On the basis of the work Northern Ireland it is estimated that for depths of peat between 5 ft and 20 the cost of bog blasting is about 25 per cent less than that of mechanical cavation.

Jetting

If the peat is too stiff for it to be displaced by the weight of the embankm alone, it can be softened by using jets to impregnate it with water. This proc needs special equipment and a plentiful supply of water; it can only be emplo on a limited range of fill material. In the usual method of jetting, an emba ment is built across the peat and the water jets are directed through the fill i the peat below. The jets are sunk rapidly to the bottom of the peat and th slowly withdrawn. Alternatively, the jets are used to inundate the fill mate with water so that the peat is displaced by the increased weight of the emba ment. This method has been used extensively by the Michigan State Highv

(A) USE OF FLEXIBLE CONSTRUCTION OVER PEAT
(The road was re-shaped to a uniform profile a year previously)

(B) A TYPICALLY UNDULATING HIGHLAND ROAD OVER PEAT, SURFACED IN WATERBOUND MACADAM
(The humps in the road profile usually coincide with rock outcrops, the peat having settled in between the humps)

PLATE 1

SEVERE CASE OF WAVINESS OF A CONCRETE ROAD OVER PEAT

PLATE 2

RUSHWOOD AND TIMBER FASCINES LAID BELOW THE BASE OF A TRUNK ROAD OVER PEAT

PLATE 3

(A) PEAT BREAKING THROUGH THE SURFACE OF A ROAD BUILT OF STONE PITCHING AND WATERBOUND MACADAM

(Fascines, gorse or turf mattresses are normally used to prevent this)

(B) AN EMBANKMENT OVER PEAT BEING CONSTRUCTED FROM TURVES CUT FROM THE HEATHER MATTRESS ON THE ADJOINING GROUND

PLATE 4

A) A CONCRETE ROAD IN NORTHERN IRELAND BEING BUILT OVER DEEP PEAT WHICH HAS BEEN PARTIALLY EXCAVATED SO THAT THE SLABS 'FLOAT' ON PRE-CONSOLIDATED PEAT

) A ROAD OVER PEAT PARTIALLY IN CUT AND PARTIALLY ON EMBANKMENT

(The outer side, which is on embankment, has fallen away and had to be made up; this form of maintenance is expected to re-occur regularly)

PLATE 5

THE USE OF STONE WALLS TO GIVE SUPPORT TO THE SIDES OF A BOG RAMPART

PLATE 6

DEFORMATION OF A HEAVILY-TRAFFICKED DUAL-CARRIAGEWAY ROAD OVER PEAT BEING REGULATED BY BUILDING UP TO LEVEL WITH FRESH MATERIAL

(A 6-ft deep open drainage ditch was cut alongside the fence on the left and the peat under the road has been continually pushing outwards from the carriageway and into the trench. Settlement of the surface varied mostly between 6 in. and 2 ft in a period of 6 months, although at one point it dropped 6 ft in the same period.

PLATE 7

(A) THE COLLAPSE OF THE EDGE OF A ROAD OVER PEAT INTO A SIDE DRAINAGE DITCH

(The section in the foreground has been strengthened with a stone wall)

(B) THE USE OF DOUBLE-DRAINAGE DITCHES TO CONTROL THE MOISTURE CONTENT OF THE PEAT UNDER THE ROAD

(The outer ditch is 50 ft from the road; the inner ditch is immediately adjacent to the verge)

PLATE 8

Department.[11] Cushing and Stokstad[9] describe another method in which the jetting of the peat is carried out in advance of the construction of the embankment.

Bateman[14] reports that jetting is particularly suitable for the displacement of deep deposits of soft peat. According to Colley[7] the method does, however, tend to leave pockets of peat which cause subsequent settlements. Although Bateman considers that jetting can be more effectively controlled than blasting methods, experience gained with blasting in recent years suggests that the latter process is quite satisfactory in this respect.

In Northern Ireland, where jetting has recently been used in conjunction with bog blasting, it was found to be both an effective and a convenient method. Not only did it speed up the work considerably, but in some sections of deep peat the embankment could be advanced for considerable distances at a satisfactory pace without any need for blasting.

CARRYING THE ROAD ON PILES

Pile foundations can be used to transfer the weight of a road over peat to the firm strata below. They have been used chiefly in Holland, and Dibbits[6] describes two examples. One was a main street in Rotterdam which was laid on some sand fill supported by a wooden floor, the floor itself being supported by wooden piles. Another example was near Hazerswoude, where a concrete floor was laid directly on wooden piles; this was also surmounted by a sand fill on which the road was constructed. No special measures were adopted to distribute the reaction between the pile head and the concrete floor over an increased area of the concrete. In another instance where the concrete slab formed the road pavement itself, the concrete was extended in the form of a series of columns to join the wooden piles below the water-table. In this way the wood was protected from rotting. Two cases[15][16] are reported of the use of piles in America; the spacing of the piles was varied, between 5 and 10 ft.

Pile foundations are expensive but in some cases there is no satisfactory alternative method of construction. All settlement is eliminated and there is a minimum disturbance of the existing peat layer during construction. The method is therefore particularly suitable for use in built-up areas where the proximity of buildings and public services such as water mains, gas, and electricity, etc., buried under the road make the use of other methods difficult.

DIRECT CONSTRUCTION ON THE PEAT

It is cheaper in first cost to lay a road directly over the peat. Severe differential settlements can usually be expected to occur, however; such movements usually extend over many years so that the road tends to have a bad riding surface and is expensive to maintain.

Flexible pavements

In Great Britain most roads over peat are of the flexible type of construction and of these most are in areas of light traffic. They are normally subject to progressive loss of shape and cracking of the surfacing. Many are old roads originally built in waterbound macadam and made up from time to time as required.

One well-known road over peat is the old Glencoe road,[17] which was built by laying a thin crust of sand and gravel from adjacent moraines directly on the peat. Many highland roads are of this form. They usually settle appreciably where they traverse areas of peat, even where the peat is not deep (Plate 1(A)). Where pockets of peat alternate with outcrops of rock distinct and uncomfortable undulations occur (Plate 1(B)). Where there is a continuous area of peat the road sometimes settles fairly evenly so that the surface retains a good shape. These features are also found in the more modern highland roads of conventional flexible-type construction, such as the new Glencoe road.

In East Anglia waterbound macadam roads have been constructed over areas of fen peat. The roads are usually about 16 in. thick and are covered with a surface dressing or a bituminous carpet. They often settle unevenly, the total settlement amounting to as much as 18 in. Hanrahan[18] has reported that flexible-type construction is predominant in bog roads in Ireland. Some of these roads show transverse and diagonal undulations with variations in the surface level of as much as 9 in. in 20 ft. Other defects are brought about by the cutting of peat close to the road for use as fuel, leaving the road on an embankment or 'bog rampart'. Hanrahan has also noted that distortion of the road surface can be reduced to a certain degree by increasing the thickness of the road structure to 1 ft 6 in. or to 2 ft, but further increases in thickness give no improvement. For roads in Shetland the minimum thickness laid is 1 ft 4 in.

On heavily-trafficked roads greater thicknesses of construction are normally used but severe deformation of the surface is common. Construction on peat is relatively cheap in initial cost and any necessary repairs, although frequent, can usually be carried out in a straightforward manner.

Rigid pavements

Both plain and reinforced concrete slabs have been used in the construction of roads over peat. Since such roads are usually about half the thickness of flexible roads, or less, their smaller weight should normally result in less settlement. In addition, light- and medium-trafficked concrete roads over peat tend to develop less abrupt longitudinal undulations than do flexible pavements. Cracking and severe loss of shape may eventually occur, however, (see Plate 2) especially when traffic increases; in this case, not only is the use of concrete high in initial cost, but it is expensive to repair.

In Northern Ireland a common practice in areas of peat is to lay doubly reinforced concrete slabs 8 in. thick either directly on the peat or on a sub-base of material taken from old waterbound macadam roads. The slabs are usually about 50 ft long, either 10 or 20 ft wide, and are dowelled at the joints. These roads usually behave reasonably satisfactorily under moderately light traffic. Longitudinal waviness is common but relatively little structural cracking occurs. The importance of dowelled joints or of constructing slabs to the full width of the road is shown by the fact that differential settlement of adjacent slabs usually occurs when dowel bars are omitted. More recently the deformation on some of these roads has, however, become sufficient to merit total reconstruction, although many still continue to give satisfactory service.

Practice in East Anglia has been to use both reinforced and unreinforced concrete construction for minor roads over peat. In general, the performance of these roads has been good. An inspection carried out on slabs laid between 6 and 13 years previously showed that unreinforced slabs 8 in. thick were particularly free from trouble if the maximum length of slab was limited to 12 ft.

In Scotland the use of concrete on main roads over peat has given reasonably satisfactory results. The traffic intensities on these main roads are, however, much smaller than those in more populous areas. On the Perth-Inverness road[19] an 8-in. double-reinforced concrete surfacing was laid, additional support being provided by reinforced beams 18 in. deep, under the edges and joints. No noticeable settlement of this road has occurred after 26 years. The concrete road at Spean Bridge on the Fort William-Inverness road was built of slabs of doubly reinforced concrete 8 in. thick, thickened to 15½ in. at the outside edges; the road has settled considerably, although its riding qualities have remained reasonably good. Another concrete road in the Highlands, that between Newtonmore and Laggan Bridge, was of doubly reinforced concrete 8 in. thick, and settled so unevenly that it had to be covered with a bituminous surfacing. In the only known case in which concrete was used for a road over peat carrying frequent and heavy traffic, movement of the structure was, however, continually taking place and the road was in frequent need of repair.

In general, concrete appears to have been reasonably successful when used for the construction of lightly-trafficked roads over peat, but the risk of failure is sufficiently high in the case of medium- and heavily-trafficked roads that it is doubtful whether its use can often be justified. The use of special heavily constructed slabs may be adequate for medium traffic; there is an indication that heavier construction than that at present employed, or prestressed concrete, might possibly be suitable for heavily-trafficked roads.

Sandwich construction

This term is used to describe a form of construction originally adopted at Schipol Airport[20] in which a bituminous surfacing and flexible base are laid on a continuous concrete slab resting on the subgrade. The object of the construction is to protect the concrete from temperature stresses and so avoid the necessity for expansion joints, and to enable the concrete to carry a greater load owing to the load-spreading of the flexible layers. The method has been applied to the construction of a trunk road over peat in Bedfordshire[21] in which a 6-in. jointless concrete slab was laid underneath a layer of flexible materials several feet thick, consisting of brick rubble, sand and a bituminous surfacing. No report is available on the performance of this road since it was constructed; settlement that occurred during the constructional period, however, was such as to warrant the laying of only a temporary surfacing.

In principle, this form of construction has much to recommend it and it would be useful to have further experience of it in roads over peat. For the purpose of reducing the load on the peat, the amount of flexible material over the concrete should be kept to a minimum, however, and, on the occurrence of any distortion or differential settlement, adjustments to the road profile should as far as possible be carried out by re-shaping the flexible layer without the addition of further material.

Construction of a lightweight raft

Roads over peat carrying light traffic are sometimes composed of a layer of lightweight material or raft, carrying a thin flexible surfacing. This method of construction is expensive and the raft is seldom thick enough to give much buoyant support to the surfacing. Such rafts do help, however, in keeping settlements small and they are of particular value where a road has to be widened with as little disturbance as possible of the adjacent peat.

Fascines. Fascines of brushwood or logs form the traditional raft construction (Plate 3). They must be kept below the water-table, otherwise they will rot. Hanrahan[18] has mentioned a mattress of brushwood and heather which rotted almost completely in five years. On the other hand, Dibbits[6] has referred to a mattress of brushwood and logs, kept under water, which is still in existence after about 4000 years.

The objects of fascines are:

(i) To provide a certain amount of buoyancy for supporting the road crust.

(ii) To spread the weight of the road as evenly as possible over the peat and so reduce differential settlement.

(iii) To prevent fill material penetrating the surface of the peat and sinking into it (Plate 4(A)).

Royer[22] has described a typical fascine mattress used in Holland. It consists of two frameworks of logs set 2 ft 6 in. apart, the space between being filled with loose brushwood, laid criss-cross in three layers. The frameworks are constructed by cording together 5-in. and 7-in. diameter logs or fascines, in a grid-patterned network. In Great Britain thinner mattresses are usually used and cording of the fascines is no longer usual. In a typical case birch trunks, hazel boughs and thorn bushes were laid loosely in a criss-cross pattern to a thickness of 8 in. More carefully prepared mattresses, described by Henry,[23] are made only of hazel wood (which does not rot in water) and the raft is constructed from bundles 10 ft long and 9 in. in diameter, consisting of 1 to $1\frac{1}{2}$-in. sticks bound tightly together. In forest areas a corduroy construction of one or two layers of fir trees 2 to 3 in. in diameter is sometimes used. Alternatively, heather may be bound around 2-in. poles to form a bundle 1 ft in diameter. According to Colley[7] corduroy rafts and also wooden planks are used in the U.S.A., although only on minor roads. A considerable amount of labour is involved in making and laying fascines; the process is costly and is slowly dying out in most areas.

Fascines are often used under fairly deep embankments; in such cases their function is probably to prevent sinking of fill material rather than to reduce the load on the peat. Dibbits[6] describes a road of this sort built in Holland on a fascine mattress 3 ft deep which settled 1.13 metres (3 ft 8 in.) in $8\frac{1}{2}$ months.

In another example, near Gouda, mentioned by Dibbits, the road crust was originally only 1 ft thick and was laid on fascines. The mattress settled 3.8 metres (12 ft 6 in.) in six years, in the course of which the road level had to be raised several times. On the other hand, in other areas of Holland, fascines have been used successfully for both main and secondary roads. One typical road between Gorinchem and Dordrecht was surfaced in concrete. Although long undulations developed, most of the road could be travelled along at a speed of 100 km/h (62 mile/h) and even on the worst stretches a speed of 70 km/h (43 mile/h) could be maintained.

Dried peat

Dried peat compressed into tight bundles which float in water is sometimes used as filling material so that there shall be little or no increase of the load on a peat subsoil.[24][25] Dibbits[6] records the use of rectangular bundles of a standard size for widening a road over very soft peat close to some buildings. A ditch alongside the existing road was filled with the bundles and the road

surface built on top. On being immersed, the peat bundles absorbed water of an amount equal to $1\frac{1}{2}$ times their own weight during the first year, but no further absorption took place. Furthermore, the bundles did not swell during the absorption process and their specific weight remained below unity.

Dried peat bundles have for many years been used in Norway to form a mattress underneath railways, and bundles measuring 1 m $\times$ 0.5 m $\times$ 0.5 m (3 ft 3 in. $\times$ 1 ft 8 in. $\times$ 1 ft 8 in.) are specially manufactured for this purpose. Their use is primarily to resist frost-heave. Haugh(26)(27) has found that well-made bundles compress by about 8 per cent of their total thickness under the weight of the railway track and this compression is complete within two years. Dried peat bundles are fairly expensive to produce (the cost of those in Norway was 5*s*. each in 1948) and their application to road construction is therefore at present limited to rather particular circumstances in which their expense can be justified.

Other lightweight materials

Other materials have been used to produce a lightweight form of construction. One such material is a mixture of sludge and granulated slag from blast furnaces, which has been used under a railway track over peat in Holland.(28) A trial with a similar material in some road construction in Scotland was, however, a failure.

As an alternative to the use of fascines, the British Forestry Commission has laid straw bundles under some gravel roads. The bundles are made by wrapping straw around poles of 2 to 3-in. diameter until a bundle of 12-in. diameter is obtained. The bundle is then secured by thin wire and coated with bitumen. The success of this method cannot yet be judged.

Turves (Plate 4(B)) are sometimes cut from the heather mattress which commonly covers areas of peat and these are laid as a foundation for any gravel stone or fill material used in the construction of the road. In both Scotland and Ireland the practice is often to bind the turves with a layer of clay or fine gravel 'soling'.

Methods of lightweight construction are of particular application to lightly-trafficked roads, where the road structure necessary for supporting the traffic does not need to be very thick. It is, however, desirable in any road built directly on peat that the dead load should be kept to a minimum. Fascines do not fit readily into modern methods of road construction and it may be profitable to investigate the possibilities of lightweight concrete and other materials.

Partial excavation

When the depth of peat is too great for total excavation to be considered, partial excavation to a depth of 2 to 4 ft is sometimes carried out and the road laid in a shallow cutting. The peat under the road will have been pre-consolidated to some extent by the weight of its previous overburden and the net increase in weight on the peat due to the new road structure will thus be reduced to a minimum. This principle has been adopted both with rigid and with flexible types of construction in Northern Ireland (Plate 5(A)).

It should be noted, however, that a considerable thickness of peat is required to be removed or replaced by lightweight material if any significant reduction in the load on the subgrade is to be made. Thus, since partial excavation removes the normally tough surface turf of peat, it is inadvisable to carry out such work unless an appreciable depth can be excavated.

Construction on an embankment

Heavily-trafficked roads over peat are often built on an embankment. This method of construction may lead to large settlements, of which many examples have been given. Thus an embankment 8 ft high on 33 ft of peat[6] settled nearly 4 ft before the final surface was laid and thereafter settled some 6 in. per year. On the road across Lochar Moss in Dumfries-shire a 5-ft embankment settled 2 ft in the first two months, a further 1 ft in the next year and 6 in. in the next four years, after which the settlements were very small; parts of the road are below ground level and are waterlogged in winter. Markwick[8] has referred to the settlement of a road in East Anglia on 25 ft of soft peat. The road frequently required making up and on each occasion the rate of settlement increased rapidly at first and then fell away as the crust subsided to the general water level of the surrounding fen.

Where the peat is merely being consolidated by the embankment no great damage may ensue from raising it, but if the increased load causes the peat to be displaced sideways the structure may become unstable[10] (see Plate 5(B)). Hanrahan[18] has reported a case where a road over peat subject to flooding was raised 2 ft on an embankment, whereupon it immediately and suddenly subsided 3 ft. de Nie[29] has dealt with railway embankments on peat where largely the same problems occur as on roads. Cuperus[30] recommends using pore-water pressure measurements in the peat to control the rate of construction of an embankment. It is clear that control of this type should always be a feature of any major works involving the construction of main roads on embankments over peat. Otherwise not only may large quantities of fill material be wasted but unsatisfactory unstable conditions may develop which are difficult to put right. By installing pressure gauges in the peat a check can be made to see that the excess pore-water pressures generated by placing a layer of fill material on top are largely dissipated before the next layer is added.

Where funds do not permit the use of special methods or where the depth of peat is very large, construction on an embankment usually becomes the final

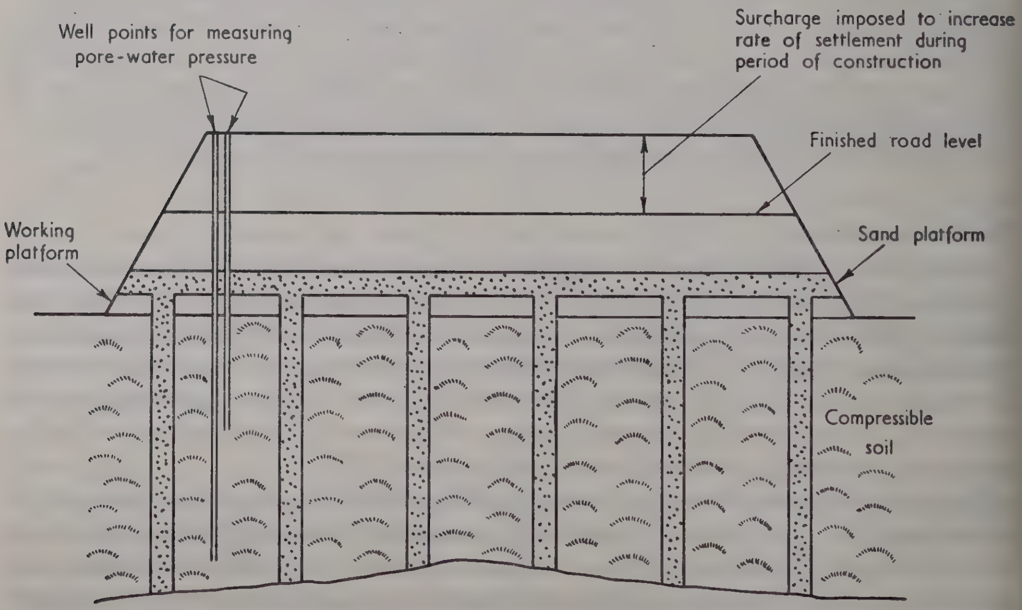

FIG. 8. DIAGRAMMATIC REPRESENTATION OF VERTICAL SAND DRAINS

alternative when building a heavily-trafficked road over peat. As some differential settlement should normally be expected, a flexible surfacing is advised. Major slips and sinkage of the embankment are the chief things to guard against and 'slow construction' should normally be adopted.

Accelerated settlement

Porter[31] in the U.S.A. has been a pioneer in the use of vertical sand drains (Fig. 8) sunk in compressible soils under embankments: such drains cause most of the settlement of the embankment to take place within 12 months or so and increase its stability. The least depth for which vertical drains are normally used is about 15 ft, although most work has been confined to ranges of depth between 30 ft and 60 ft.

Stanton[32] has described the construction of vertical sand drains in California and has published a typical specification for this type of work. He quotes twenty-two projects in which sand drains were used during the period 1934-1947. Five different methods of installation (Fig. 9) were adopted: (i) rotary drill; (ii) rotary jet; (iii) driven mandrel; (iv) jetted mandrel, double-wall type; (v) jetted mandrel, closed-end type.

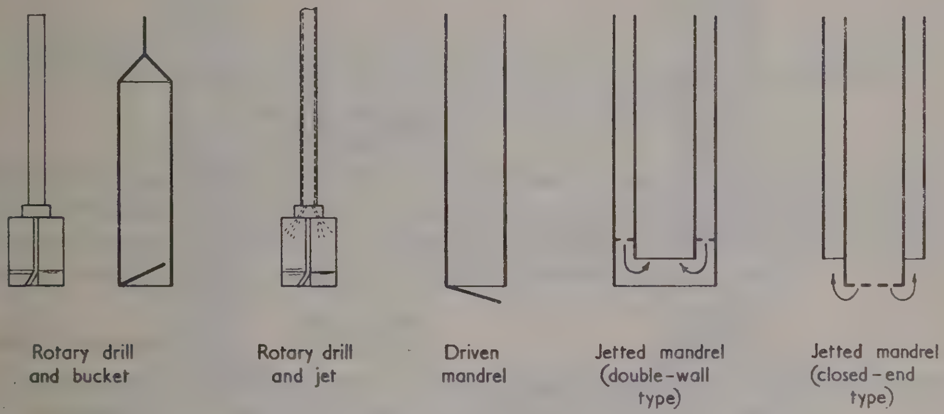

FIG. 9. DIAGRAMMATIC REPRESENTATION OF VARIOUS METHODS OF INSTALLING VERTICAL SAND DRAINS

Fairly heavy equipment is used for constructing the drains, so a working platform of fill material is usually placed over the swamp in sufficient depth to support the equipment. When the sand drains are installed the working platform is covered with a layer of sand so that the expelled water can escape from the drains to the edges of the embankment. Normal fill material is laid on top of the sand layer until the required height of the embankment is reached. The diameter of drains used in California varies between 14 in. and 30 in. and they are usually spaced at approximately 10-ft centres. The cost of their installation in 1946 was about 1 dollar per linear foot (7*s*. per ft). Stanton quotes the details of settlements for two typical projects: in one the road was laid 11 months after the start of construction, in which time the embankment had settled $5\frac{1}{2}$ ft, the original depth of compressible soil being 60 ft; in the other, an embankment constructed over a 40-ft depth of compressible soil settled $2\frac{1}{2}$ ft during the 7 months it was being built, and there was negligible subsequent settlement. Stanton insists that proper design and close control of the work are essential to success. During the

course of construction the settlement of the embankment is continuously measured and well-points, fitted with pressure gauges, are installed in the compressible layers to measure the pore-water pressure. By means of these measurements the rate of loading of the embankment can be controlled and undesirable foundation movements are avoided.

Kjellman[33] has described a method developed by the Royal Swedish Geotechnical Institute, in which cardboard drains are used in place of sand drains (Fig. 10). The cardboard is in bands 4 in. wide and $\frac{1}{8}$ in. thick, which can be rolled on a drum and inserted into soft ground by means of a metal guide. The

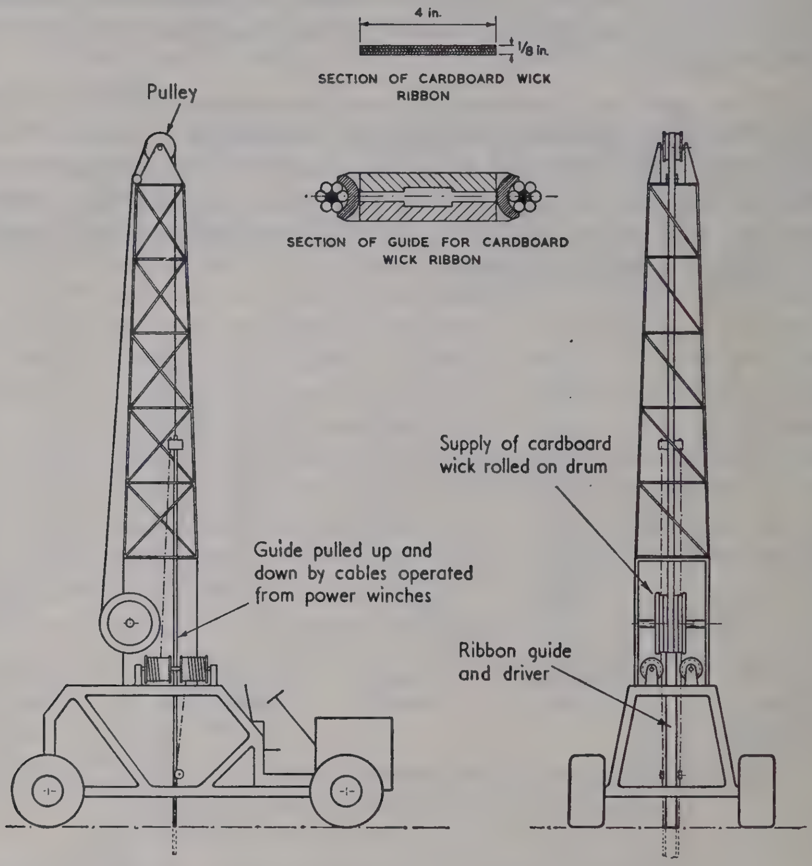

FIG. 10. DIAGRAMMATIC REPRESENTATION OF THE KJELLMAN CARDBOARD WICK DRAIN DRIVER

drain-driver is mounted on a large 28-ton vehicle with a tall mast to accommodate the driving tube, which can insert drains to a depth of 20 m (65 ft). Although the necessary spacing of the drains is usually about 4 to 5 ft (as compared with approximately 10 ft for vertical sand drains), the work of installing them is very rapid and a working speed of one drain every 40 seconds has been reached. The cost in 1947 was approximately 1.50 Swedish crowns per metre length of drain installed (8*d.* per ft), which is considerably less than the cost of sand drains. It is likely, however, that such a machine could be used economically only on extremely large sites.

In America, Saad[34] has reported the development of porous concrete piles, consisting of porous-walled pipe, as an alternative to sand drains. He claims

that the concrete pipes are easier to install, are unaffected by shearing stresses which may develop in the peat, and appear to be less easily choked by fine material. The concrete drainage piles can be of a much smaller diameter than sand drains and, although they have not been used in road construction, Saad has estimated that they would be 30 per cent less expensive than sand drains.

Rapid settlement of an embankment may also be produced by making it higher than is finally intended and removing the excess material when the expected settlement has taken place. This method is normally used in conjunction with vertical drains[32] but Dibbits[6] has described the procedure in Holland without such drains. The rate of construction is controlled by measurements of pore-water pressure.

Methods of accelerating settlement have in practice been used chiefly in construction over highly compressible marshy soils rather than over peat itself. The consolidation characteristics of peat and the relatively small depths in which it is found (usually less than 25 ft) do not always justify the use of vertical drains. These methods have, however, been very successful on many occasions and their use has become frequent and widespread in their country of origin, the United States of America.

ANCILLARY METHODS OF PROVIDING SUPPORT FOR ROADS OVER PEAT

The methods described below are normally used in conjunction with other more general methods of construction over peat. They are designed to provide additional support for the road, either by some form of stiffening or stabilizing the peat itself, or by introducing some form of external support.

Lateral support

Lateral support can be given to a road by installing sheet piling in the peat or by constructing a berm of fill material along the side of the road.

Sheet piling is usually used to protect buildings from any disturbance that may occur in a peat layer when a road is built over it, but additional support to the road is provided at the same time. Cuperus and de Nie[35] have referred to the use of steel sheet piling at the sides of a low railway embankment over peat where it passes through the town of Gouda. The use of sheet piling connected by tie-rods on either side of a railway has been reported by Duffie.[36] Dibbits[6] has used strut piles to form a pile-screen. A more general method, in which vertical sheeting is used as a support to the road, has been described by Henry.[23] It was used with a light reinforced concrete raft laid directly on the peat. The raft distributes the vertical load and the sheeting distributes the consequent side thrust on the peat. The use of thin 18-gauge sheeting, preferably corrugated, is suggested for this. The sheeting is likely to perish, however, and there are no records from which the effectiveness of this type of construction may be assessed.

Cuperus and de Nie have also described the use of wide side berms or haunches of sand to strengthen a railway track constructed over very soft peat. The railway track had to be raised because of continual settlement, but there had been experience of serious slips of the track in the area and further slips

were feared. Sand was therefore dumped in trenches alongside the railway to increase the resistance to sliding of the underlying soft layers.

Peat or turf banks and wide verges are sometimes advocated to provide lateral support in the construction of highland roads over peat. Stone-filled trenches are also used.

In parts of the Republic of Ireland, too, stone walls 2 ft wide have been built in the peat, along the edges of the road. Gravel has also been used in walls 3 ft thick. The walls are usually carried down to firm strata to 'contain' the peat under the road completely; if the peat is more than 4 to 5 ft deep, however, the walls are usually built to this depth and further stone is added at the top as the stones sink into the peat. Stone walls have also been used along the sides of bog ramparts (Plate 6).

Another method which has been recently tried in Northern Ireland is known as 'cladding'. In this method, clay or gravel haunches are laid against the sides of bog ramparts with the object of minimizing any seasonal moisture changes in the peat under the road. The weight of the haunches is, however, liable to induce movement of the peat and consequently of the road structure.

Of the various methods considered, the construction of low, wide berms adjacent to the road appears to be the most practical and successful.

Drainage measures

It is common practice to lay fairly deep, open ditches along the side of roads constructed over peat (Plate 7). This is to drain the upper layers of peat and make them firmer. Although the shear strength of the peat is thus increased, the process is a slow one and there is considerable volume shrinkage of the peat, resulting in settlement. Furthermore, the construction of ditches removes a certain amount of lateral support for the road and peat is often found to have been pushed into them (Plate 8(A)). Other disadvantages are that the trenches usually require frequent maintenance and regrading and may have to be extended for considerable distances to obtain a suitable outfall, since peat often occurs in low hollows.

In Shetland, because it is considered that drainage is important in increasing the shear strength of peat, a system of shallow, double-drainage ditches has been devised with the object of maintaining the moisture content under the road at a uniform and reasonably low value throughout the year (Plate 8(B)). An outer ditch 50 ft from the road removes excess surface water so that the inner ditch adjacent to the road runs at a fairly constant depth of water throughout the year and so minimizes alternate swelling and shrinkage of the peat under the road.

Experience in the Hebrides suggests that drainage in advance of the construction of the road is important, although the danger is recognized of removing lateral support by digging ditches too deep. Some engineers consider, however, that no attempt should be made to drain the peat under a road and that any ditches necessary for the removal of surface water should be as shallow as possible.

Figures of the amount of settlement that can occur due to the shrinkage or wastage of peat when drained are given by Chatwin.[37] A layer of fen peat 22 ft deep, which was drained and cultivated, had its surface lowered by 4 ft 9 in. after 12 years and it fell a further 5 ft 11 in. after a further 72 years.

It is suggested that only very shallow drainage of peat should be carried out close to a road; general drainage other than for the removal of surface water

should not normally be undertaken, although it may be satisfactory if it is carried out well in advance of the construction of a road. If this is done, however, care should be taken to see that the lateral support to the road is not reduced and that the peat foundation is not liable to undergo severe seasonal movements of moisture through being unduly exposed to atmospheric effects.

Surface support

The use of fascines often involves the loss of the natural strength of the surface mattress of peat, which is normally removed. Although this surface mattress may be able to support a depth of fill of several feet, Terzaghi and Peck[38] recommend that its continuity should be destroyed before the fill is placed as it might otherwise prolong the period of settlement or suddenly break at some future date. There are, however, differences of opinion on this subject. The practice in the Highlands of Scotland and elsewhere is to do the reverse and to lay fresh turf wherever the surface mattress is broken or removed.

Shaw[39] has described the successful use of metal tracks to bind the surface of peat and so avoid cracking of a thin flexible surfacing laid above it. On a lightly-trafficked road in Ross and Cromarty numerous pockets of peat extending for about 15 to 20 yd were encountered. On these sections the 6-in. thick sand/gravel road stabilized with bituminous emulsion cracked badly within a month of being laid. Other areas on which metal track was laid proved to be satisfactory. The track consisted of heavy, wire-mesh netting secured to transverse steel rods $\frac{3}{8}$ in. in diameter at intervals of 15 in.

In using turf or other materials for providing surface support for a road, the most logical method is to regard the surface mattress as a means of preventing parts of an embankment or road structure sinking separately into peat. The settlement of the whole road structure, however, should be as uniform as possible. It is suggested, therefore, that the mattress should be kept intact beneath the road but should be severed from adjacent areas of peat.

MAINTENANCE OF ROADS CONSTRUCTED OVER PEAT

Maintenance costs of roads over peat are abnormally high. With flexible-type construction, various methods may be adopted for dealing with the undulations in the road surface that commonly occur. The cheapest method in initial cost is to fill, either completely or partially, any depressions that occur. The extra load so imposed, however, usually produces further settlement and further frequent maintenance is required in the future. An alternative method, often used in the Republic of Ireland, is to remove the humps in a road rather than to fill in the depressions. This is more costly in initial expenditure but no extra load is imposed on the peat and future movement is minimized. A compromise sometimes adopted is to remove the worst humps and then to further improve the road profile by making up part of the depressions with a very small amount of added material.

Both in Scotland and in Ireland,[18] the importance of maintaining a sealed surface on roads over peat is recognized, although in some areas resources do not permit this. Where peat breaks through the road crust, engineers have recommended cutting out a shallow patch and laying hessian cloth and a light

infilling of sand before placing any stone. The importance of keeping ditches and culverts clear is also recognized.

In the case of concrete, small changes in level can often be remedied by superimposing a bituminous surfacing, but where failure is serious complete reconstruction may be the only satisfactory treatment in the long run.

In maintenance as well as in the initial construction, the prime object should be to provide as uniform conditions as possible throughout the length of the road.

CONCLUSIONS

Although this review reveals that much knowledge has already been accumulated about methods of road construction over peat, it does not enable definite conclusions to be drawn about the relative merits of different forms of construction as they apply to conditions in Great Britain. There is clearly an urgent need for full-scale trials to be made under controlled conditions, in which different forms of construction can be compared in relation both to performance and to cost. Little is known about the mechanical properties and behaviour of peat beneath roads and it will be necessary to investigate this aspect of the problem in detail in parallel with the full-scale road trials.

A detailed examination of some existing roads is also needed to find the reasons for differences in behaviour.

SUMMARY

The general properties of peat have been briefly described and the course of action of an engineer who has to construct over peat has been discussed.

Existing methods of construction adopted in areas of peat have been reviewed under the following headings:

- Removal of the peat and replacement by fill material
  - Mechanical excavation
  - Displacement by gravity
    - End tipping
    - Asymmetrical side tipping
    - Symmetrical side tipping
  - Bog blasting
    - Trench-shooting
    - Toe-shooting
    - Underfill blasting
  - Jetting
- Carrying the road on piles
- Direct construction on the peat
  - Flexible pavements
  - Rigid pavements
  - Sandwich construction
  - Construction of a lightweight raft
    - Fascines
    - Dried peat

No definite conclusions can be drawn about the relative merits of different forms of construction as they apply to conditions in Great Britain. There appears to be a need for various methods to be compared under controlled conditions in full-scale trials. There is also a need for the properties of peat to be studied in detail in relation to the behaviour of different forms of construction.

It is usually cheaper in first cost to construct roads directly over the peat but with these methods severe differential settlements often occur, the movements extending over many years so that the road has a bad riding surface and is expensive to maintain; this applies particularly to heavily-trafficked roads. Methods in which the peat is removed and replaced by good fill are usually very expensive in initial cost and sometimes impracticable, but they ensure a sound road foundation.

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Printed in Great Britain under the authority of Her Majesty's Stationery Office by
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